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WL-TR-94-2008

**Development of Laser Velocimetry for the
Measurements of Turbulence Intensity and Flow Velocity
Ahead of a NGV Row in a Full-Stage Rotating Turbine**



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SEPTEMBER 1993

FINAL REPORT 1985-1993

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SEP 1993 FINAL
DEVELOPMENT OF LASER VELOCIMETRY
FOR THE MEASUREMENTS OF TURBULENCE INTENSITY
AND FLOW VELOCITY AHEAD OF A NGV ROW IN A FULL-STAGE
ROTATING TURBINE

DR. MICHAEL G. DUNN

C F33615-85-C-2566
PE 61102
PR 2307
TA S3
WU 18

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This is a letter report which summarizes the six tasks of this effort. It was not possible to complete shock tube measurements as originally planned due to schedule conflicts, equipment failures, and finally an explosion in Calspan's lab. The funding was to expire in 1993, which would have incurred an additional obligation of the government if the effort were to be completed as originally planned. By mutual agreement, in order to prevent incurring any additional cost, the design, fabrication, calibration and installation of heat flux gages on the Advanced High Work turbine hardware was substituted for the only uncompleted task of the effort, that of actually running the shock tube test. The documentation of the delivered hardware's performance will be reported in the appropriate ATARR test report of the Advanced High Work Turbine. The resulting new instrumentation from this modification to the Statement of Work is shown as installed on the Advanced High Work Turbine in photos.

INTRODUCTION

This document represents a letter final report for the Calspan UB Research Center (CUBRC) contract no. F33615-85-C-2566. There have been many delays in completing the final task (the shock-tunnel experiments) of this effort, all of which have been formally documented. The most recent plan that Dr. Rivir and I had agreed to was to run the experiments beginning the week of 26 July 1993. When we made these plans, I noted that for several reasons (one of which was that it was an opportunity to check out the entire ATARR software package prior to the then planned XF120 full-stage experiments and in this way work out potential problems in the software system in advance) I wanted to complete running the unsteady heat transfer and pressure measurements on the SSME fuel side turbine prior to initiating the laser experiments. The SSME experiment was on schedule and I anticipated no difficulty in meeting the July 26 date. As planned, the SSME turbine was installed in the Calspan Turbine Test Facility (TTF) in early June and calibration of the pressure transducers was initiated. During this calibration, our sample-time recorder failed and the external trigger unit of the Data Laboratories Transient Recorders also failed. Without these two pieces of equipment, the experiment couldn't be performed. We devoted some time to working these problems and were able to fix the Data Laboratory Recorders. However, the sample-time recorder couldn't be repaired and we were forced to order a replacement. The promised delivery on the new unit was 26 August 1993 which would still have been acceptable. The SSME measurement program was planned for about five days of running which would make for a tight schedule to install the Garrett 731-2HP turbine and to run the laser measurements. On 4 August 1993, the LENS facility with which we share the laboratory, encountered a mechanical failure during high-pressure operation. The LENS facility itself was essentially undamaged, but there was significant damage to the surrounding buildings and utility services. An investigation is currently in progress regarding the cause of this incident, and building repairs are ongoing. Progress is being made very rapidly to put the building and necessary services back into a condition that would allow operation of the TTF. However, it is very difficult to be sure just when it will be possible to operate again. Under the circumstances, there is a high probability that it won't be possible to complete the SSME experiments prior to the end of the first week in September. It would still be possible to install the Garrett TFE 731 turbine and run the WPAFB experiments, but everything would have to go according to plan in order for us to complete the work in time to meet the contract deadline. I would like to complete the laser experiments under discussion here because I feel that they are just as important today as they were when we initially decided to do them. Dr. Rivir was advised of the low probability of completing the effort in time to have all invoices paid prior to 30 September 1993, and a modification to the contract was suggested which would provide instrumentation for similar measurements to be performed in the ATARR at WPAFB. The obvious suggestion that was eventually agreed upon was that CUBRC would design, construct, and calibrate heat-flux gage inserts for the Advanced High Work Turbine (AHWT) vane which is the next experiment planned for running in the ATARR. The remainder

of this report is devoted to a review of the Statement of work under which the program was conducted and, in the process, a description is given of the contractual items that have been completed. It will be demonstrated that except for one item the SOW has been completed in total, and that a portion of that one item has been completed.

The SOW from Contract No. F33615-85-C-2566 is contained in SECTION C-DESCRIPTION/SPECIFICATIONS which is reproduced below in total.

SECTION C - DESCRIPTION/SPECIFICATIONS

Calspan - UB Research Center Unsolicited Proposal dated November 1984 and entitled "Development of Laser Velocimetry Measurement of Turbulence Intensity and Flow Velocity Ahead of a NGV Row in a Full-Stage Rotating Turbine (Unsolicited Proposal No. 102)" is herein incorporated by reference.

The CUBRC proposal to which SECTION C refers reads as follows: The effort described in this proposal would be performed jointly by personnel of the Calspan-UB Research Center and WAL. It is planned that items 1-4 and 6 given below would be completed during the course of this program. Items 1-6, including 5, are reproduced below for the sake of completeness. The work that is not described explicitly in any of the Items 1-6 but which was explicitly understood by both me and Dr. Rivir is that we would perform the shock-tunnel experiments.

- (1) Spot alignment with the velocity vector requires significant improvement for the shock-tunnel measurements. This could be achieved by using an available blower to supply an airflow of the proper velocity to the NGV inlet annulus.
- (2) The data recording system in use did not have the required frequency response dictated by the experiment. A means of sampling and holding 10^5 samples for each of two photo-multipliers over the 15 to 20 millisecond test time would be a tremendous aid in interpreting the effect of changes in system settings. By having these data samples in memory, the data could be analyzed in great detail in a post-run analysis mode.
- (3) Additional data for optimizing the LTA need to be obtained in the AFTT shock tube, but at pressures, temperatures, and densities more representative of those associated with the full-scale turbine model.

- (4) Seed materials with vaporization temperatures greater than that of propylene glycol need to be investigated further because of the relatively high (1000°R) total temperature associated with the shock-tunnel measurements. Dow 200 was used at Calspan, but calibration runs using this material were not made in the AFTT shock tube.
- (5) An independent measurement of the turbulence intensity is desirable. The second techniques used here of heat-flux measurements for a cylinder in cross-flow provides an approximate value but a hot-wire technique would likely provide a more convincing standard with which to compare the LTA measurement.
- (6) Additional shock-tube measurements need to be performed in order to obtain a comparison of the turbulence intensity as a function of the number of good data samples for different turbulence levels.

SUMMARY OF ACCOMPLISHMENTS

The status of each of the items of the statement of work noted above will be reviewed in this section. Of the 6 SOW items, CUBRC was to complete 1, a portion of 2, all of 5, and the experiments which were not explicitly called out as an item and Dr. Rivir was to complete a portion of 2, 3, 4, 6, and help at CUBRC with the experiments. ITEM (1) A blower was obtained on loan from Calspan and the velocity measurements discussed in this Item were performed. A brief report describing this effort was prepared by CUBRC and is available. ITEM (2) Dr. Rivir attended to this problem and the required data recording system was procured. In addition, between the time that this proposal was written and now Calspan brought on line the very large Turbine Test Facility (TTF) which increased the available test time from 15 milliseconds to 40 milliseconds. This factor of almost 3 increase in test time prompted us to move the place of the intended experiment from the 48-inch shock-tunnel to the TTF. An analysis of how this would be done was undertaken and completed. A report describing this effort is available. ITEM (3) It is my understanding that Dr. Rivir performed these experiments in conjunction with a graduate student thesis at AFTT and that a document describing the results is available. ITEM (4) It is my understanding that Dr. Rivir also performed these experiments at AFTT, again as part of a graduate student thesis and that the results are available. ITEM (5) An independent technique (the hot-wire anemometer was selected) for measurement of turbulence intensity and scale in short-duration facilities was investigated at CUBRC. Measurement of turbulence intensity in short-duration facilities is a matter of general interest at both Calspan and CUBRC because of the many turbomachinery-related research programs on-going within these organizations. As a result, funds were obtained from Calspan and CUBRC IR&D sources for the basic development of this diagnostic technique. The cylinder in cross flow is an old technique that has

been used in the past at Calspan, and such a cylinder is available for the Garrett TFE 731-2 turbine. However, as noted above, the alternate technique that was investigated here is the hot-wire measurement. As part of the IR&D effort noted above, a TSI 1750 constant temperature hot-wire anemometer system was purchased and this unit was calibrated in a test rig designed and built to duplicate the flow environment equivalent to that anticipated in the turbine. A technical report describing this effort was prepared and is available. ITEM 6 Once again, this is a task that Dr. Rivir was to perform using the AFIT shock-tube facility. I assume that this task has been completed. This completes the 6 specific tasks that are called out in the proposal document.

The final remaining task that was to be completed was to perform measurements in the Calspan TTF to obtain fundamental data regarding the local flow velocity and the turbulence level upstream of the NGV row. Because of difficulties described herein, those experiments will not be performed. Instead, a modification to the Statement of Work has been mutually agreed upon which states that CUBRC will design, construct, calibrate, and install heat-flux gauges on the Advanced High Work Turbine hardware. The resulting new instrumentation from this modification to the Statement of Work is shown as installed on the Advanced High work Turbine in Figures 1 through 4. Figure 1 shows the pressure surface heat transfer gages and Figure 2 the suction surface heat transfer gages. Figures 3 and 4 show the end wall button heat transfer gages. Figure 4 has the vane removed. Documentation of the gages and actual measurements under simulated turbine conditions will be presented in an appropriate ATTAR test report.

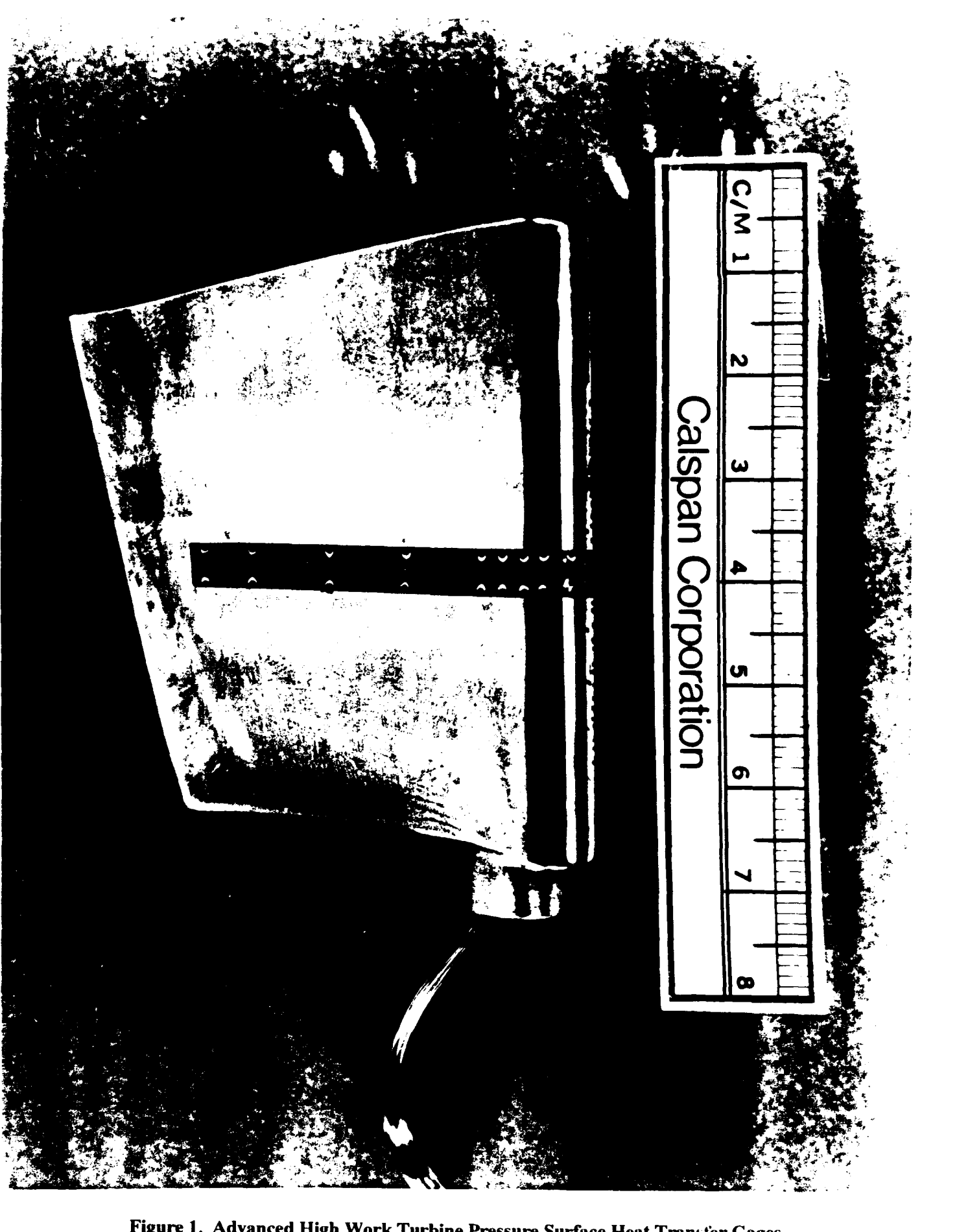


Figure 1. Advanced High Work Turbine Pressure Surface Heat Transfer Gages

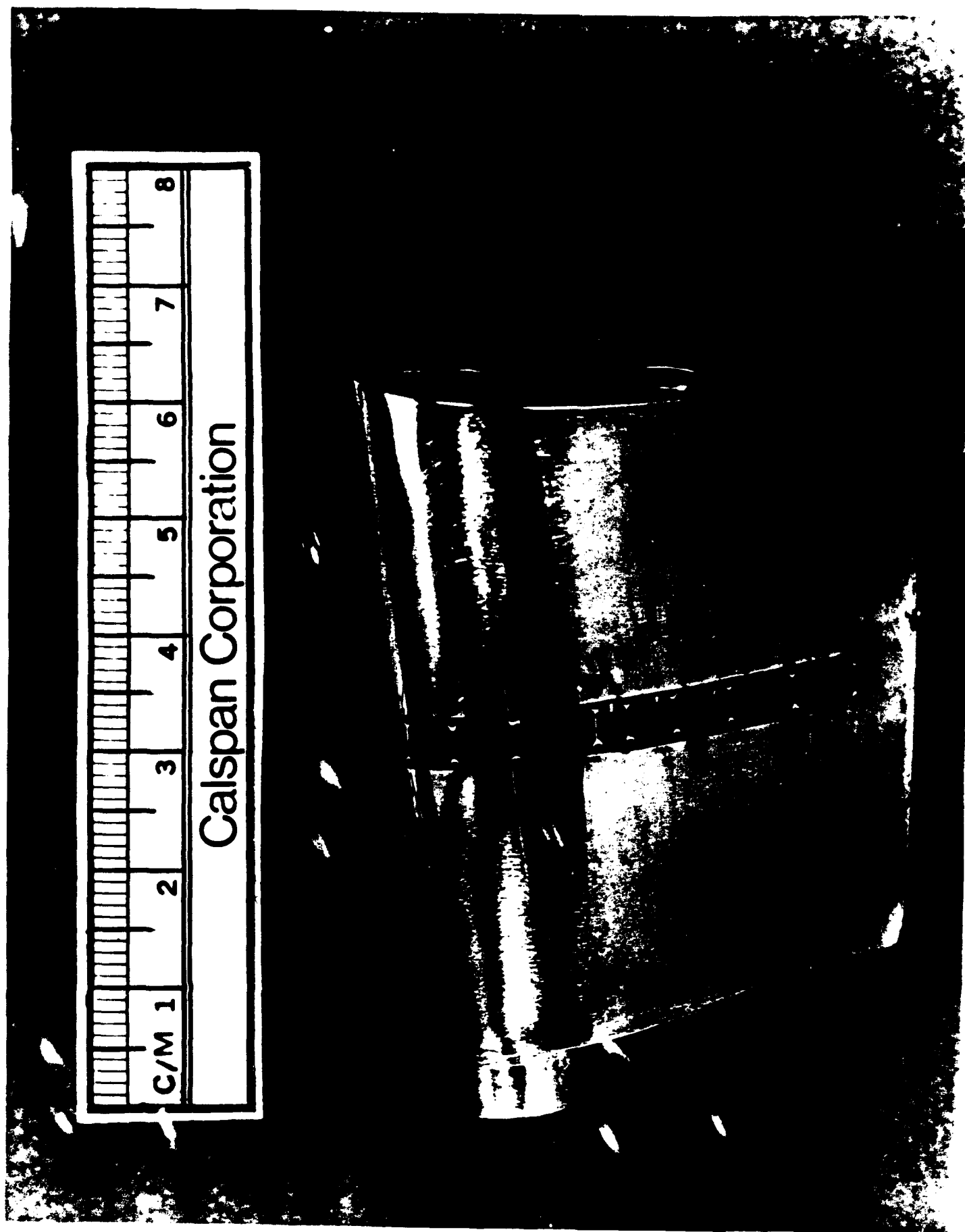


Figure 2. Advanced High Work Turbine Suction Surface Heat Transfer Gages



Figure 3. Advanced High Work Turbine End Wall Heat Transfer Gages, Vane In Place

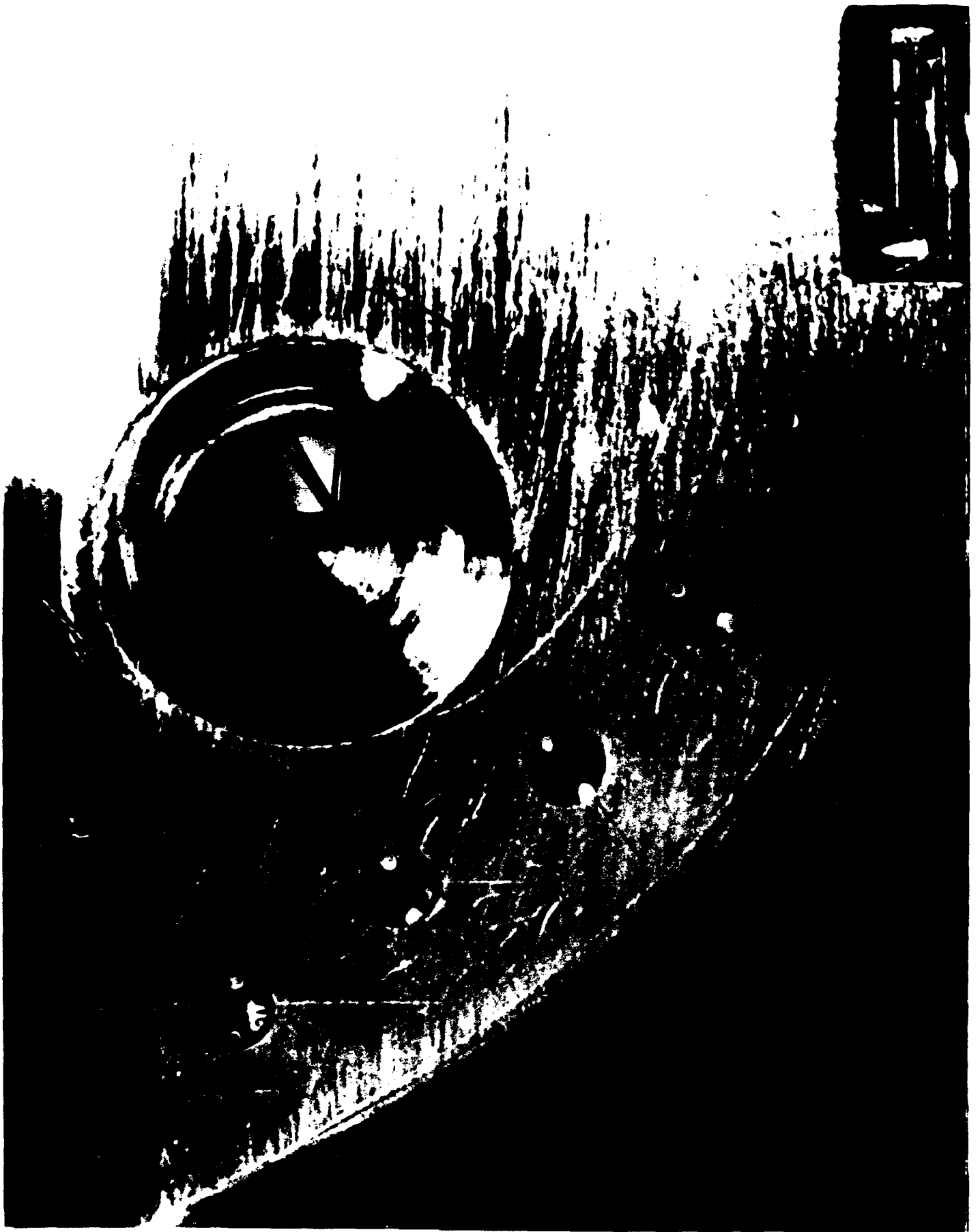


Figure 4. Advanced High Work Turbine End Wall Heat Transfer Gages, Vane Removed